(Dr. Arch Park's presentation at 6-13-79 luncheon at Pecora Symposium)

REMOTE SENSING MILESTONES

• WW II	DEVELOPMENT OF CAMOUFLAGE DETECTION FILM (C.I.R.)
• 1953	COLWELL DEMONSTRATED DISEASE DETECTION PUBLISHED IN 1956
• 1956	SOVIET PUBLISHED PAPER ON USE OF SPECTRAZONAL PHOTOGRAPHY FOR MAPPING SOILS
• 1961	WILLOW RUN LABS (ERIM) BUILT AN AIRBORNE MULTI-SPECTRAL SCANNER
• 1963 (CIRCA)	ITEK BUILT A NINE LENS CAMERA
• 1963	NAS STUDY FOR USDA ON USE OF MILITARY RECONNAISSANCE DEVICES FOR AGRICULTURE
• 1964	NASA PROGRAM DEFINITION

REMOTE SENSING MILESTONES

NASA PROGRAM INSTRUMENT TEAMS

- CAMERA TEAM
  - 150 MM METRIC MAPPING
  - 300 MM LARGE FORMAT (225X450) METRIC MAPPING
  - 600 MM PANORAMIC
  - 150 MM MULTIBAND
- INFRARED TEAM
  - SINGLE THERMAL BAND (8-14 μm)
  - MULTI CHANNEL THERMAL SPECTROSCOPY
  - MULTISPECTRAL SCANNER
- MICROWAVE TEAM
  - L, C, X, Ku, Ka BAND SLAR
  - L, C, X PASSIVE RADIOMETERS

EARTH RESOURCES SURVEY PROGRAM

(1964 - 1972 NASA SR&T PROGRAM)

- APPLICATIONS DEFINITION
- LABORATORY RESEARCH - FIELD RESEARCH - A/C RESEARCH
- LANDSAT DEFINITION (67)
- APOLLO EXPERIMENT (69) S-065
  - MULTISPECTRAL CAMERA ~ LANDSAT SPECTRAL INTERVALS
  - PROOF OF CONCEPT

EARTH RESOURCES SURVEY PROGRAM

LANDSAT DEFINITION

USDI

- ORBITAL CHARACTERISTICS
- PAYLOAD - R.B.V.
  - 2 WITH 100 METER G.R.D. (RED & IR)
  - 1 WITH 25 METER G.R.D. (PANCHROMATIC)
  - CARTOGRAPHIC ACCURACY
  - LATER GREEN, RED AND IR CAMERAS

USDA

- 9:30 EQUATOR CROSSING
- M.S.S.
  - REPRODUCE C.I.R.
  - RADIOMETRIC ACCURACY

EARTH RESOURCES SURVEY PROGRAM

LANDSAT DEFINITION

TRADES:

- MORPHOLOGY SHADOWS VS. HIGH SUMMER SUN
- CLOUD COVER VS. TIME OF DAY (f) LOCATION
- FREQUENCY OF OBSERVATION VS. FOV
- FREQUENCY OF OBSERVATION VS. SPATIAL RESOLUTION
  - (f) COMPLETE COVERAGE
  - (f) BANDWIDTH OF STADAN NET
  - (f) STATE OF ART RECORDERS

EARTH RESOURCES SURVEY PROGRAM

LANDSAT DEFINITION

RESULTS:

- 18 DAY COVERAGE - COMPROMISED SEVERAL APPLICATIONS

  E.G. SNOW SURVEY - DECIDED NOT TO DO IT

  - EVEN TWO SATELLITES NOT FREQUENT ENOUGH

- GIVEN 18 DAYS ALL OTHER PARAMETERS SET
  - F.O.V. = 185 KM AT EQUATOR WITH 10% SIDELAP
  - PHOTON LIMITED MSS AT 80 METER SPATIAL RESOLUTION AT 6 BIT ACCURACY
  - STADAN NET = 20 MBITS MSS = 16.5

EARTH RESOURCES SURVEY PROGRAM

LANDSAT DEFINITION

- GLOBAL REPETITIVE CYCLE SELECTED
- ORIGINAL SPATIAL RESOLUTION WAS DEFINED AS A RESULT OF THE TRADE STUDIES
- SPECTRAL INTERVAL (100 nm) DEMANDED BY ORBIT
- BAND CENTERS CHOSEN TO REPRODUCE C.I.R.
- THEMATIC MAPPER BAND CENTERS DEFINED AT SAME TIME
- VISIBLE SPECTRUM SLIGHTLY MODIFIED AS A RESULT OF LATER RESEARCH

SENSOR PARAMETERS AFFECTING DATA ANALYSIS

1) SPATIAL RESOLUTION

2) SPECTRAL RESOLUTION

3) SIGNAL-TO-NOISE RATIO

SPATIAL RESOLUTION

- IT IS GENERALLY NOT POSSIBLE TO MEASURE THE ENERGY RADIATING FROM A GIVEN MATERIAL UNLESS THE MATERIAL OCCUPIES A SIGNIFICANT PORTION OF THE INSTANTANEOUS FIELD OF VIEW (IFOV)
  - N.A.S. STUDY STATES 60 PIXELS
  - LANDSAT 1 $\simeq$ 60 ACRES
  - LANDSAT-D $\simeq$ 10 ACRES
- SPATIAL RESOLUTION IS THE PRINCIPAL PARAMETER IN MENSURATION

SPECTRAL RESOLUTION AND S/N

- INFORMATION THEORY (IEEE, 1968) "PROBABILITY OF CORRECT CLASSIFICATION = (f) MEASUREMENT COMPLEXITY"
- MEASUREMENT COMPLEXITY = (n) SPECTRAL BANDS X SIGNAL QUANTIZATION PRECISION
- SIGNAL QUANTIZATION $\sim$ S/N

MEASUREMENT COMPLEXITY

- LANDSAT 1 = 4 BANDS X 64 = 256
- LANDSAT-D = 7 BANDS X 256 = 1792

IMPROVEMENT FACTOR = 7

SPECTRAL RESOLUTION AND S/N

- THEORY ASSUMES COMPLETE (INFINITE) KNOWLEDGE OF CLASSES
- PRACTICAL PROBLEM IS FINITE
- THEORY SHOWS A DEFINITE INFLECTION (POINT OF DIMINISHING RETURNS)
- PHENOMENON HAS BEEN OBSERVED IN AIRCRAFT ANALYSIS

SPECTRAL RESOLUTION AND S/N

- INTRINSIC DIMENSIONALITY = FOUR (VISIBLE AND NEAR IR) (MSS)
- POTENTIAL DIMENSIONALITY = SIX (ADD MIDDLE AND THERMAL IR) (TM)
- PROBABLE DIMENSIONALITY OF TM DATA

  FEATURE A = BANDS 2, 4, 5, AND 6

  FEATURE B = BANDS 1, 3, 6, AND 7

  FEATURE C = BANDS 2, 3, 5, AND 7

SIGNAL-TO-NOISE

6 BITS = VEGETATION VS. BARE SOIL VS. WATER

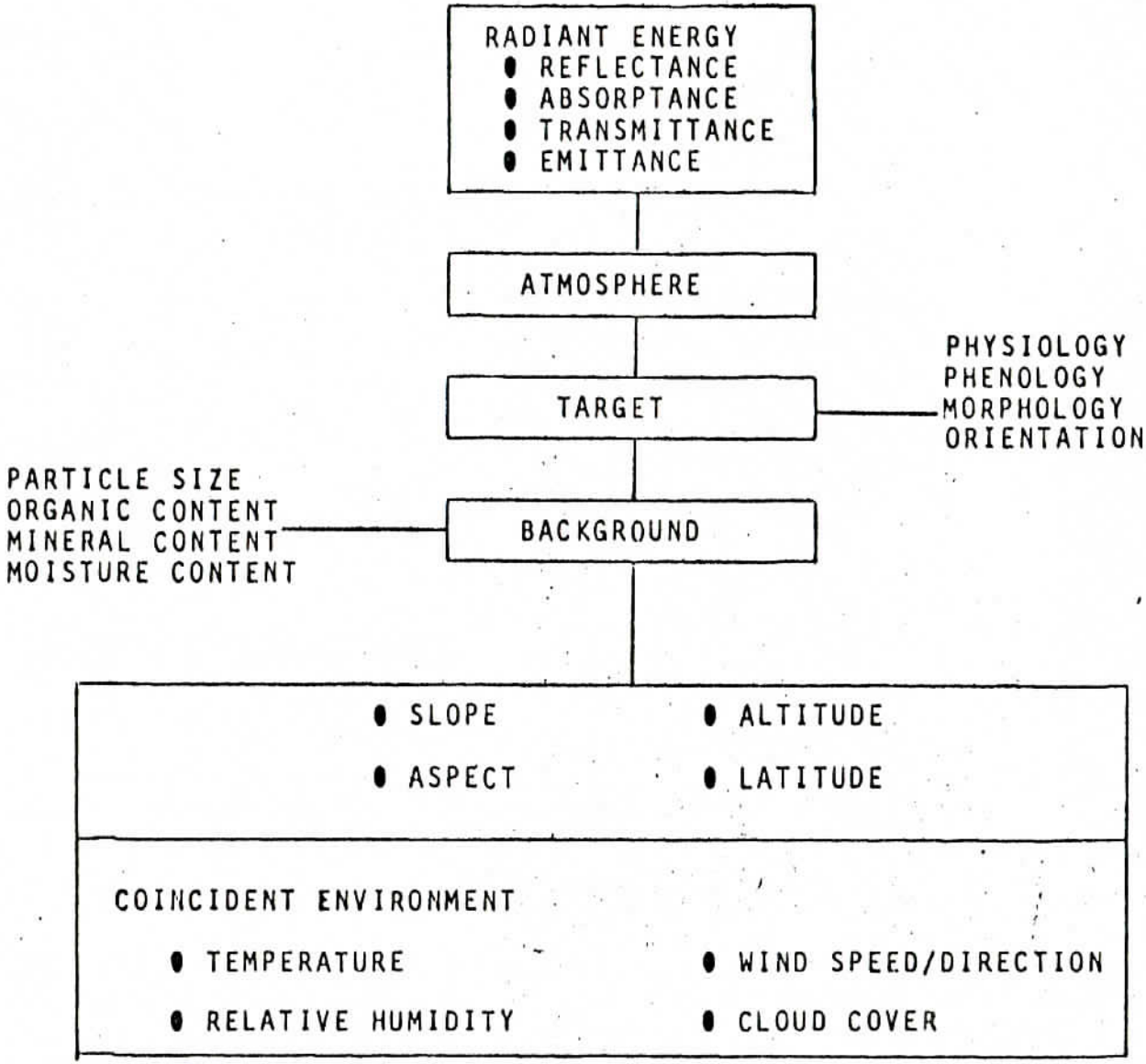
7 BITS = CROP SPECIES DISCRIMINATION

8 BITS = CEREAL GRAIN DISCRIMINATION

AND

ABILITY TO USE THE ADDITIONAL SPECTRAL DIMENSIONALITY

MEASUREMENT MODEL



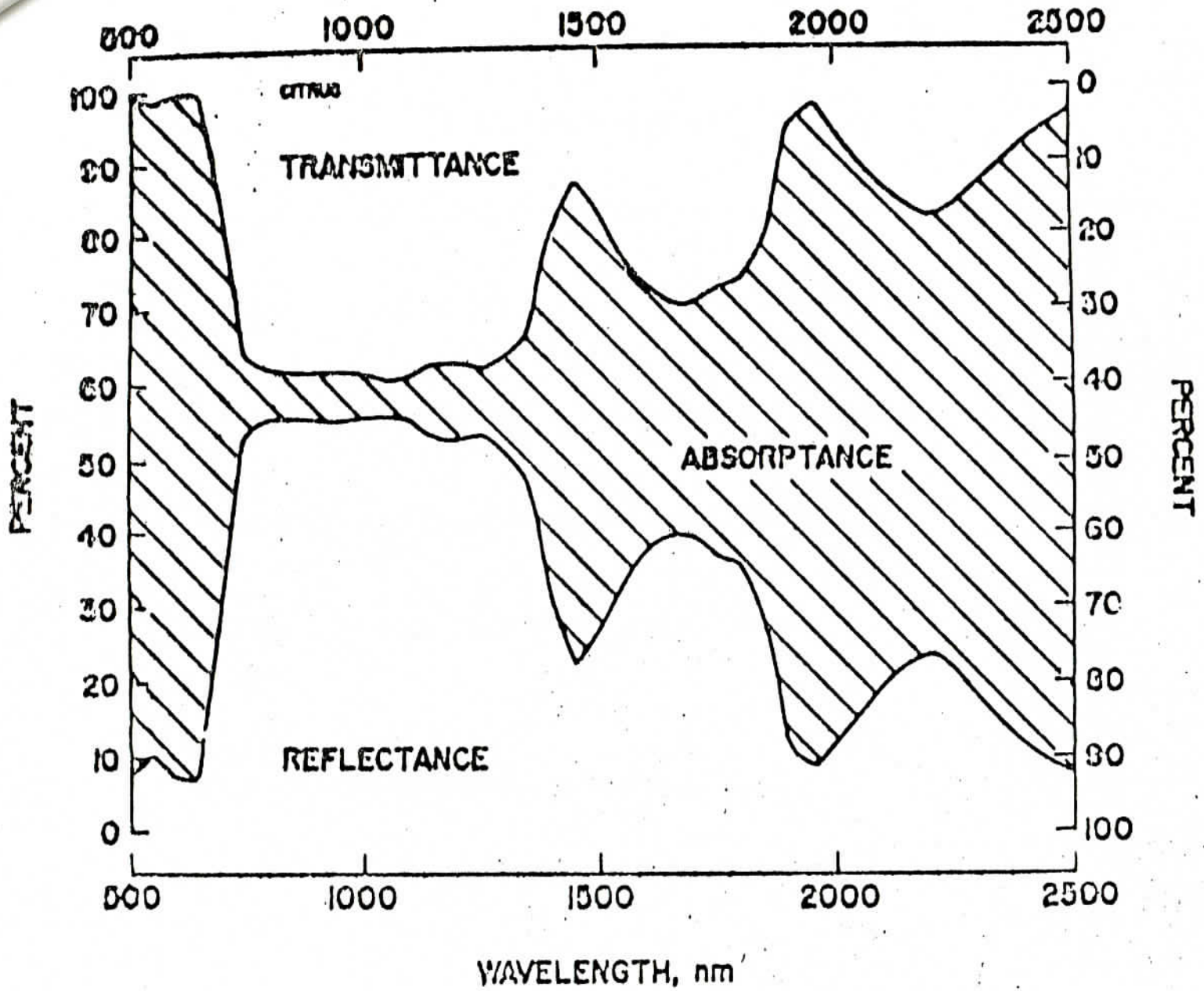


Figure 5. Diffuse reflectance, transmittance, and absorptance [100 - (percent transmittance + percent reflectance)] of the upper (adaxial) surface of a mature orange leaf (Citrus sinensis (L.) Osbeck).

MSS MEASUREMENTS

BAND 4 = GREEN/YELLOW = PLANT PIGMENTS

BAND 5 = YELLOW/RED = CHLOROPHYLL ABSORPTION

BAND 6 = NEAR INFRARED = LEAF, TURGOR*

BAND 7 = NEAR INFRARED = LEAF TURGOR

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* TURGOR = INTRACELLULAR WATER PRESSURE

Table 2. THEMATIC MAPPER SPECTRAL AND RADIOMETRIC CHARACTERISTICS

BAND	WAVELENGTH (um)	NEΔρ	BASIC PRIMARY RATIONALE FOR VEGETATION
TM 1	0.45-0.52	0.008	Sensitivity to chlorophyll and carotinoid concentrations
TM 2	0.52-0.60	0.005	Slight sensitivity to chlorophyll plus green region characteristics
TM 3	0.63-0.69	0.005	Sensitivity to chlorophyll
TM 4	0.76-0.90	0.005	Sensitivity to vegetational density or biomass
TM 5	1.55-1.75	0.01	Sensitivity to water in plant leaves
TM 6	2.08-2.35	0.024	Sensitivity to water in plant leaves
TM 7	10.4-12.5	0.5K	Thermal properties

MEASUREMENTS

- ALL MEASUREMENTS ARE RELATED TO PLANT GROWTH AND CONDITION
- SOME MEASUREMENTS ARE SIGNIFICANT IN TERMS OF SPECIES
  E.G. CHLOROPHYLL ABSORPTION IN RICE
- NONE OF THE MEASUREMENTS IS CONSISTENTLY UNIQUE EITHER WITHIN A FIELD OR BETWEEN FIELDS TO BE A CANDIDATE FOR A "SIGNATURE"
- DISCRIMINATION IS RELATED TO BOTH SPECIES AND STAGE OF GROWTH
- IDENTIFICATION BECOMES POSSIBLE USING TIME AS THE DISCRIMINANT IN A PHENOLOGICAL MODEL

EPISODE SENSOR SYSTEM

BIOLOGICAL SIGNIFICANCE

- MSS BANDS 4, 5, (6 OR 7) AND (7/6)
- 0.1% CHANGE = PHYSIOLOGICAL EFFECT
- 1.0% CHANGE = CANOPY EFFECT
- 10% CHANGE = PLANT COMMUNITY EFFECT

VEGETATION RESOURCE MANAGEMENT

- IDENTIFY AND MEASURE FOOD CROP PLANTS
- MODEL FOOD CROP PLANT GROWTH
- STRESS MODEL DEVELOPMENT
- MODEL YIELD
- IDENTIFY AND MEASURE TIMBER
- ECOZONE BOUNDARY DEFINITION--SIGNATURE EXTENSION
- WILDLIFE HABITAT MAPPING

LAND RESOURCE MANAGEMENT

- LAND USE CLASSIFICATION CODES DEVELOPED
  - APPROVED BY USGS, HUD, EPA, CENSUS

- PLANIMETRIC MAP PRODUCTION - 1:250,000
- THEMATIC MAP PRODUCTION - 1:100,000

} LANDSAT I, II, III

- POPULATION DENSITY/LAND USE CHANGES (CENSUS ASVT)

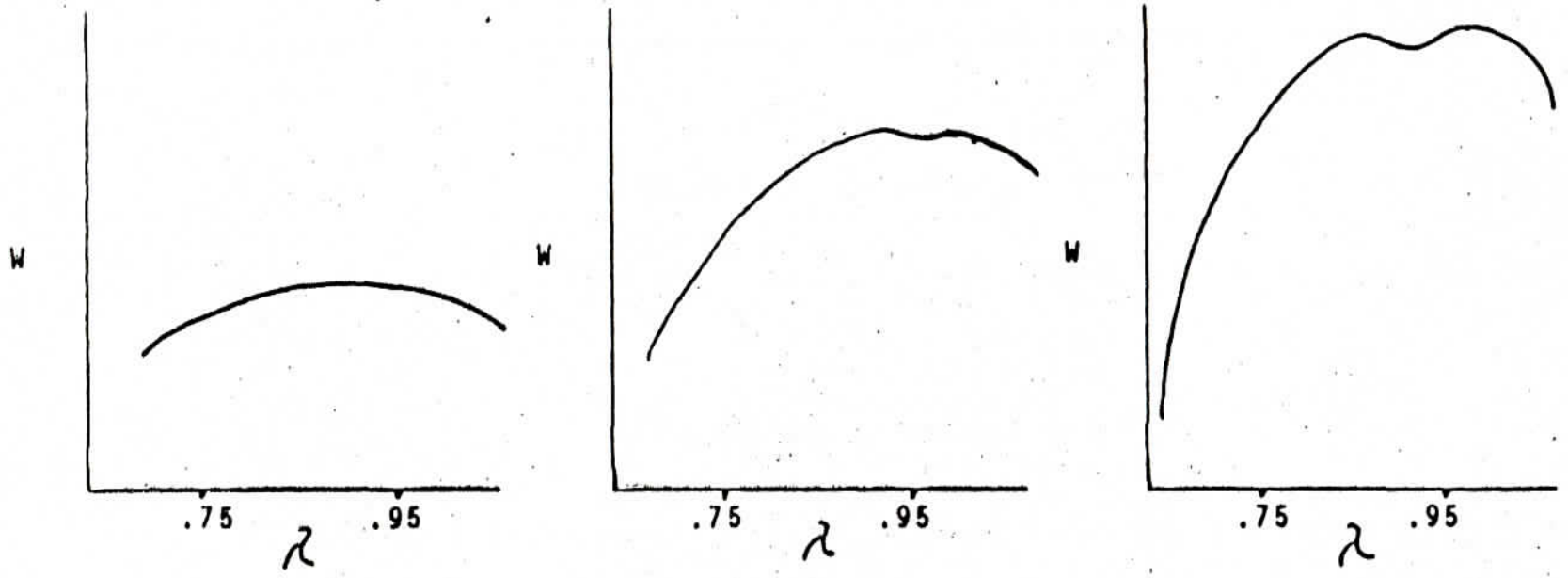
MINERAL RESOURCE MANAGEMENT

- SURVEY COST REDUCTION
- SATELLITE UNIQUE OBSERVATIONS
- GEOMORPHIC, TECTONIC/SEISMIC SURVEYS
- MINERAL/PETROLEUM PROBABILITY MODELLING
- LIMITED LITHOLOGIC MAPPING

WATER RESOURCE MANAGEMENT

- MAP SURFACE WATER
- MONITOR SURFACE WATER AREA - FLOOD - DROUGHT
- MONITOR SNOW LINE
- MAP WETLANDS
- HYDROLOGIC MODELS
  - RIVER BASIN RUN-OFF
  - SOIL MOISTURE

LEAF SPECTRA



INCREASING AGE

- RATIO 6/7 IS (f) MATURITY
- RADIANCE OF BOTH BANDS INCREASES UNTIL LAI $\simeq$ .4
- CANOPY 6/7 $\simeq$ STABLE UNTIL RIPENING
- STRESS CAUSES EARLY REDUCTION IN BAND 6 RADIANCE
- RESULTING RATIO 6/7 CHANGE IS DETECTABLE